OUT-OF-PLANE RESPONSE OF ENGINEERED CEMENTITIOUS COMPOSITE FACED BLOCK MASONRY

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Abstract- The purpose of this study is to propose and demonstrate the effectiveness of engineered cementitious composite (ECC) for strengthening block masonry. Two cases have been studied: ECC only on the tension face and ECC on both tension and compression faces. Out-of-plane response of tension reinforced beam, and both tension and compression reinforced beam has been experimentally investigated under four-point loading systems. The findings of this study show that both the strength and ductility of masonry beams enhance using ECC, which advocates the use of ECC as a block masonry reinforcing material.

Keywords- Block masonry, bending response, ECC, four-point loading.

1 Introduction

Block masonry structures are distinct from other types of structures in terms of construction techniques. Concrete blocks have been widely used because of their low cost, easy availability, and high compressive strength. However, because block and cement mortar are fragile materials, failure occurs suddenly, without warning. During the life of a building, block masonry walls are subjected to various out-of-plane loadings i.e. static and seismic loads. Therefore, it is important to design block masonry walls resilient to out-of-plane loads [1]. For the purpose of reinforcing masonry constructions, much research has been conducted in the previous decades. The majority of research studies have indicated that intact masonry walls can be strengthened in an out-of-plane direction [2].

Concrete, one of the most extensively utilized composite materials in the construction sector, is a fragile material. Numerous studies on fiber-reinforced concrete/composites have been conducted in the past, but the ECC material and technique were developed in the early 1990s [3]. Many researchers found that analytical and empirical findings for concrete block walls loaded in the lateral direction are still inadequate, and numerous retrofitting solutions have been developed to increase masonry building efficiency. The masonry walls must be built in a way that they can easily bear the external loads to ensure public safety, structural integrity, and resilience [4], [5]. The out-of-plane efficiency can be improved when ECC layers are added to the masonry walls [6]. A fully coated layer of ECC applied to the face of block masonry is predicted to improve out-of-plane efficiency, including load-bearing capabilities and ductility [7].

Thus, the objective of this research is to investigate the out-of-plane response of block masonry beams that have been externally reinforced with ECC on the tension face and on both compression/tension faces. Tests were conducted to determine the behaviors of beam-like specimens (essentially a bundle of blocks joined with mortar joints in between) under bending load [8]. The objective of the bending load test is to demonstrate the ability of the reinforcing technique to improve block masonry structural behavior. This study helps out to understand the behavior of ECC-retrofitted masonry walls against out-of-plane loads by using the proposed strengthening method.

2 Experimental Procedures

The experimental examination was divided into four distinct phases. First, the ECC was prepared. Nine masonry beams were cast, each with eight blocks in a row, and 1:3 cement mortar was used in between blocks. Beams were strengthened by ECC on the tension face and both on compression/tension (namely, sandwich). Bending tests were performed on masonry beams to determine the behavior of ECC. An overview of the experiments performed is presented in Table. 1.

Table 1: Summary of bending tests performed on beam-like specimens.

Type of tests	Specimens tested	ID
Bending Tests	Controlled masonry beam-like specimens (non-retrofitted).	A
	A beam-like specimen retrofitted with ECC layer on tension face.	B
	A beam-like specimen retrofitted with ECC layer on tension/compression faces (sandwich).	C

2.1 Constituents of ECC

In this study, ECC contains Polypropylene (PP) fibres of 12 mm in length, cement, fly-ash, sand, and water. High-range superplasticizers (SP) are used to enrich the fresh properties of the mixture. The dosage rate of Polycarboxylate SP was 1% by weight of cement used, and the filler used was fine silica sand. The fly ash/cement ratio was 1.8 (by mass), whereas the water/cement ratio was 0.28 (by volume). The sand/cement ratio was taken as 0.6 (by mass). The sand and cement are blended and dried for 30–60 seconds till the mixture is homogenous in the creation of ECC. Then fly ash and SP are added sequentially. SP was added as per requirement. To make a cake, fibres are added at the end.

3 Research Methodology

3.1 Testing of beam-like specimens

Nine beam-like specimens were manufactured and were subjected to a 4-point bending test. Each specimen has eight blocks with seven mortar joints in between, as shown in Figure 1. 5mm thick layer of mortar joint was used internally. Out of eight specimens, three benchmark specimens were unstrengthened (A series), three specimens had a 15mm ECC layer (B series) on the tension face, and three specimens were retrofitted with the ECC layer on both tension and compression faces. The length of the beam-like specimen was 835 ± 25 mm with a 400 mm width. The thickness of specimens is: 200 mm in the A-series (see Fig. 1(a)), 215 ± 5 mm in thickness for the B series (see Fig. 1(b)), and 230 ± 5 mm in thickness for the C series (see Fig. 1(c)).

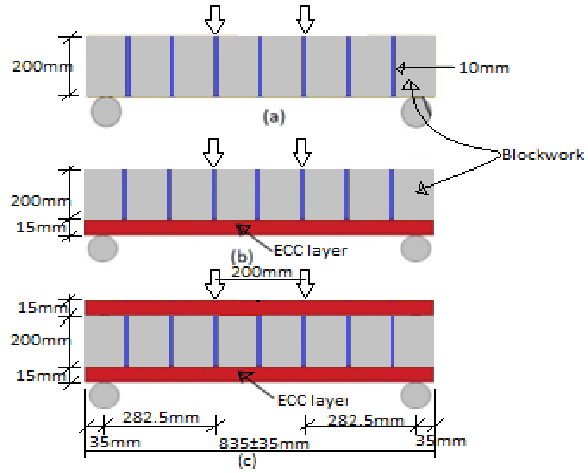


Figure 1: Schematic illustration of four-point flexure testing (a) unstrengthen specimens (A series) (b) Tension face strengthening (B series) (c) Sandwich bonded (C series)

4 Results and analysis

4.1 Unstrengthened specimen response (A series):

Figure. 2(a) explains the behavior of the un-strengthened specimens (A series). As a result, these un-strengthened specimens broke suddenly (brittle), which resulted in immediate failure of the load holding capacity. The failure occurred shortly after a fracture developed along with one of the block/mortar contacts near the specimen's middle span (inside the two areas where the load was employed). The findings demonstrate the vulnerability of un-strengthened block masonry beams to out-of-plane loading. Fig. 3(a) shows the condition of the specimens after failure.

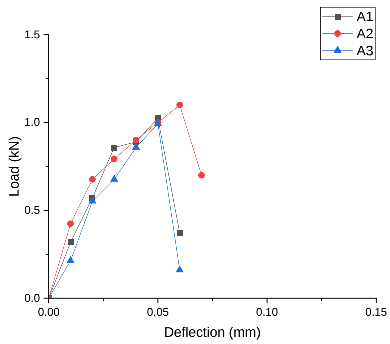
4.2 ECC strengthen specimen response (B, C):

Fig. 6 depicts the crack pattern of the beam retrofitted with ECC on the tension face (B series) after failure. It has been noted that small fractures are formed initially. These small fractures coalesce to produce a bigger fracture that finally causes the ECC layer to fail. Furthermore, specimens strengthened with an ECC layer on the tension face (B Series) have a crack pattern that is localized at the joints in between the blocks. The micro-cracks converge to form wider cracks, which eventually fail the ECC layer, causing the beam specimens to collapse. Whereas in the case of sandwich beam (C series) specimens, a big crack is produced across the ECC layers and shows brittle failure. Contrasting the crack pattern of B series and C series beams, it is evident that the specimen retrofitted on the tension face permits the ECC to acquire a more homogenous (dispersed) cracked pattern than the sandwich beam.

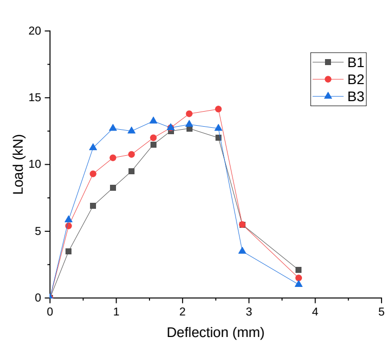
Table: 2 displays the load due to the initial fracture, load-carrying ability, and the accompanying mid-span deflection at failure. Figure: 3 shows the relationship between out-of-plane deflection and applied loading, which shows that the load-carrying capacity of sandwich beam is more than that of beam bonded with ECC on tension face (B series) and unstrengthened beam (A series). The average load due to the first fracture was determined to be 1.14 kN, 12.33 kN, and 18.19 kN for the A, B, and C series correspondingly. The average mid-span deflection at failure for A, B, and C series was 0.07 mm, 2.03 mm, and 1.55 mm, respectively. As seen in Table. 2, the load-bearing capability of the sandwich beam is greater than that of the beam bonded on the tension side. In an un-strengthened beam, failure occurs after the peak load and causes flexure failure, as shown in Fig. 3(a). B and C specimens were retrofitted with ECC, a tension face and a sandwich bonded beam. The load-carrying capacity of B and C was 10.82 and 15.96 times greater than that of the controlled block masonry beams (A), respectively. The out-of-plane deformation of B and C series specimens was 29 and 22.14 times greater than that of the un-strengthened specimens (A series), respectively.

Table 2: Summary of four-point bending test.

ID	Numbering of specimens	ECC layer thickness (mm)	Loading at first crack (kN)	Average (kN)	Loading at failure (kN)	Average failure load (kN)	Deflection at failure (mm)	Average deflection (mm)
	A1	---	1.15		1.22		0.07	
A	A2	---	1.25	1.14	1.31	1.223	0.05	0.07
	A3	---	1.01		1.14		0.08	
	B1	15.30	11.8		12.75		2.21	
B	B2	15.50	12.35	12.33	14.15	13.38	2.43	2.03
	B3	15.76	12.65		13.25		1.45	
	C1	14.95	17.95		22.40		1.34	
C	C2	15.65	17.77	18.19	18.95	20.95	1.50	1.55
	C3	15.40	18.85		21.50		1.80	



(a)



(B)

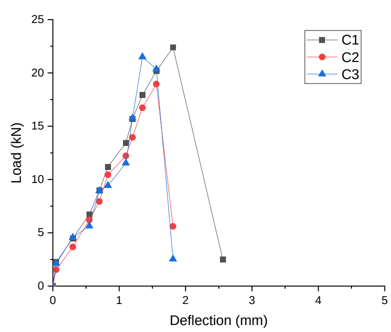


Figure 2 Load deflection responses of four-point bending test of (a) Non retrofitted specimens (A series) (b) Tension retrofitted specimens (B series) (c) Sandwich (C series)

(a)

(b)

(c)

Figure 3: Failure crack pattern of (a) Non retrofitted specimen (A series), (b) Bottom retrofitted specimen (B series), (c) Sandwich specimen (C series)

5 Conclusions

The flexural response of block masonry walls retrofitted with the ECC layer was explored in this experimental research. The following are conclusions derived from the test results:

1. Unstrengthen specimens (A series) were more vulnerable to out-of-plane loading and produced sudden failure with a maximum load-carrying capacity of 1.223kN, and mid-span deflection was 0.07mm.
2. Specimens retrofitted with ECC on tension face show enhanced load carrying capacity of 13.38kN, which is about 10.82 times of unstrengthen specimens. Mid-span deflection of tension faced retrofitted specimen increased up to 29 times the unstrengthen specimens.
3. Specimens retrofitted with ECC both on tension and compression sides (C series, sandwich) show the load-carrying capacity is 15.96 times greater than that of unstrengthen specimens, and mid-span deflection was about 22.14 times of unstrengthen specimens.
4. The load-bearing capability of the sandwich beam is 1.57 times higher than that of a beam retrofitted on tension face only and 17.13 times the un-strengthen beam-like specimen. The tension-faced ECC retrofitted specimens show more deflection than that of the sandwich and unstrengthen specimens and show more uniform cracks.

Acknowledgement

Words cannot express my gratitude to my professor Dr Faisal Shabbir for his invaluable patience and feedback. Additionally, this endeavor would not have been possible without the generous support from BSc students Muhammad Abdullah and Adnan Ashraf, who helped me in my experimental program. I am also grateful to my classmates Uzma Bibi, Fahim Abbas and Wajahat Zahoor for their editing help, late-night feedback sessions, and moral support.

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